PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : B01D 43/00, B01J 19/10

A1

(11) International Publication Number: WO 00/41794

(43) International Publication Date: 20 July 2000 (20.07.00)

(21) International Application Number: PCT/GB00/00101

(22) International Filing Date: 17 January 2000 (17.01.00)

(30) Priority Data:
9900894.8 15 January 1999 (15.01.99) GB

(71) Applicant *(for all designated States except US)*: UNIVERSITY COLLEGE CARDIFF CONSULTANTS LTD. [GB/GB]; 55 Park Place, Cardiff CF10 3AT (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: COAKLEY, William, Terence [GB/GB]; 20 Windermere Avenue, Cardiff CF2 5PX (GB). HAWKES, Jeremy, John [GB/GB]; 8 Ladysmith Road, Penylan, Cardiff CF2 5DT (GB).

(74) Agent: GIBSON, Stewart, Harry; Urquhart–Dykes & Lord, Three Trinity Court, 21–27 Newport Road, Cardiff CF2 1AA (GB).

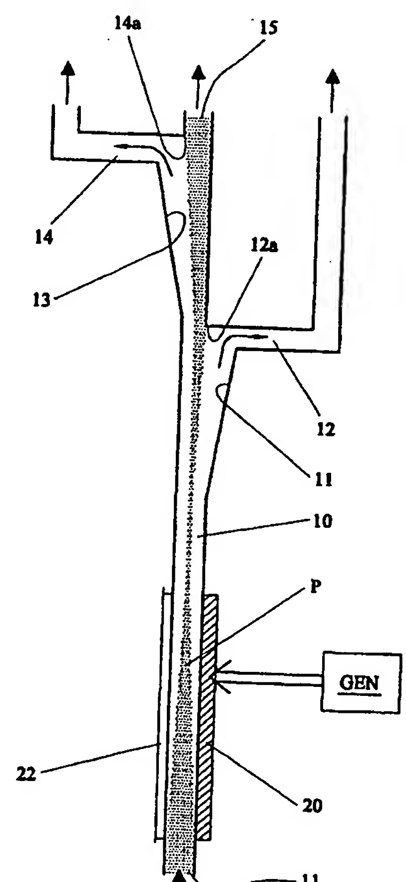
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: PARTICLE MANIPULATION

(57) Abstract

An apparatus, for performing the manipulation of particles suspended in a fluid, comprising a duct (10) for the flow of fluid in which particles are suspended, and means (20, 22, GEN) for establishing an acoustic standing wave field which extends across the width of the duct: the duct (10) is provided, downstream of the portion in which the acoustic standing wave field is present, with at least one outlet passage (12 or 14) which provides for an abrupt change of direction of the flowing fluid.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

Particle Manipulation

The present invention relates to an apparatus for and method of performing the manipulation of particles suspended in a fluid, using an acoustic standing wave field.

Our International patent application WO98/50133 discloses an apparatus for performing the manipulation of particles suspended in a fluid, the apparatus comprising a duct for the flow of the fluid in which the particles are suspended, and means for establishing an acoustic standing wave field across the width of the duct: the duct is formed with an expansion in width downstream of the section in which the standing wave field is present. In use of this apparatus, the particles in the fluid are displaced, by the acoustic standing wave field, into a series of parallel bands, located at the standing wave nodes. The particles remain in these bands as the fluid flows downstream from the section in which the standing wave field is present. When the fluid reaches the expansion of the duct, the stream of fluid expands correspondingly in width and in so doing the bands of particles are spread further apart, so increasing the spacing between adjacent bands. In passing further along the duct, the particle bands retain their increased spacing.

In the above-described apparatus, the duct may be relatively narrow in width and the operating frequency relatively high, to take advantage of the greater ease with which particles can be concentrated at high operating frequencies. However, the expansion of the duct leads to a separation of the particle bands, which is sufficient for the particle bands to be separated from the fluid. In particular, in the apparatus disclosed in WO98/50133, the duct is formed with a plurality of outlet passages spaced apart along its

length, each of these outlet passages extending outwardly at an inclined, acute angle, thus forming an expansion in width of the duct. At a first pair of such outlet passages, the fluid adjacent the sides of the duct (i.e. outwardly of the outermost bands of particles) now pass out of the duct, along these outlet passages. At a second pair of inclined outlet passages, the outermost bands of particles pass out of the duct, along these passages.

We have now devised an apparatus which provides for more effective separation of particles from a suspending fluid.

In accordance with the present invention, there is provided an apparatus for performing the manipulation of particles suspended in a fluid, the apparatus comprising a duct for the flow of the fluid in which particles are suspended, and means for establishing, in a predetermined longitudinal portion of the duct, an acoustic standing wave field which extends across the width of the duct, the duct being provided, downstream of the portion in which the acoustic standing wave field is present, with at least one outlet passage which provides for an abrupt change of direction of the flowing fluid.

Preferably the apparatus is arranged so that a single nodal plane is established in the acoustic standing wave field, generally mid-way between opposite sides of the longitudinal duct. Preferably the duct is formed with two outlet passages, in opposite sides of the duct. The particles concentrate as a planar band, located at the nodal plane of the standing wave field, and remain in this band as they flow along the duct, downstream from the portion in which the standing wave field is present. Then the fluid to either side of the particle band passes out of the longitudinal duct, through the respective outlet passages.

Surprisingly, although the outlet passages impose an

abrupt change of the direction of flow, fluid passes out through these passages without creating noticeable turbulence, and substantially free of particles. The particles themselves continue to flow along the duct, downstream of the outlet passages.

In a particular embodiment which will be described herein, each outlet passage extends outwardly at substantially 90° to the axis of the longitudinal duct. In general however, each outlet passage may extend outwardly at any angle greater than 45° (preferably greater than 60°) to the axis of the longitudinal duct. We have found that it is considerably easier to machine the outlet passages when these extend at such angles to the axis of the duct, than if the outlet passages are to extend at only a small angle: also, in the latter case, sharp points and edges are created, at the junctions between the duct and the outlet passages, and we have found that particles e.g. of dirt are liable to accumulate at such sharp points.

Preferably the longitudinal duct has a generally uniform, rectangular cross-section. Preferably each outlet passage also has a generally uniform, rectangular cross-section. Preferably the side of the duct, upstream of each outlet passage, diverges outwardly. Preferably the junction between the outlet passage and the side of the longitudinal duct, downstream of the outlet passage, is rounded off.

Preferably the duct is arranged generally vertical, for the fluid to flow upwardly along it.

Also in accordance with the present there is provided a method of performing the manipulation of particles suspended in a fluid, the method comprising the steps of providing a duct, producing a flow of fluid along the duct, the fluid having particles suspended therein, establishing an acoustic standing wave field which extends across the width of the duct, in a predetermined longitudinal portion of the duct, and

causing the fluid to undergo an abrupt change of direction into an outlet passage from the duct, at a position downstream of said portion in which the acoustic standing wave field is present.

An embodiment of the present invention will now be described by way of example only and with reference to the accompanying drawing, the single figure of which is a diagrammatic longitudinal section through an embodiment of particle separation apparatus in accordance with the invention.

Referring to the drawing, there is shown a device which comprises a longitudinal duct 10 which is of generally uniform, rectangular cross-section of 0.25 x 10mm. A piezoelectric transducer 20 is positioned on one side of the duct and the corresponding portion 22 of the opposite side of the duct is formed as a reflector. In use, a liquid or other fluid with suspended particles (e.g. biological cells) flows along the duct from an entry port 11: a signal generator GEN drives so that the transducer 20 and the transducer 20 and reflector 22 establish an acoustic standing wave field which extends across the width of the duct 10, such that a single nodal plane is established mid-way across the duct; the acoustic standing wave field is present in a predetermined longitudinal portion of the duct, corresponding to the extent of the transducer 20 and reflector 22 along the length of the duct. The particles P, indicated by shading in the drawing, are displaced transversely by the standing wave field, to concentrate in this nodal plane.

Downstream of the portion of the duct in which the standing wave field is established, the duct 10 is provided with a first outlet passage 12 which extends outwardly from one side of the duct 10 (at 90° to the axis of the duct 10, in the example shown). The passage 12 also has a uniform, rectangular cross-section of 0.25 x 10mm. Further downstream, the duct 10 is provided with a second outlet passage 14 which outwardly from the opposite side of the duct (also, in the example shown,

at 90° to the axis of the duct). The passage 14 also has a uniform, rectangular cross-section of 0.25 x 10mm.

It will be appreciated that each of the outlet passages 12,14 forms a widthwise expansion of the duct. As shown, the corresponding side of the duct is outwardly inclined over a section e.g. 11,13 immediately upstream of each outlet passages 12,14. Preferably the junction between each outlet passage and the side of the duct, immediately downstream of the outlet passage, is rounded off as indicated at 12a,14a, to minimise the risk of turbulence being created at these points.

Downstream of the portion of the duct in which the standing wave field is present, the particles remain in a single band, mid-way between the opposite sides of the duct 10. Then the fluid, to one side of the particle band, passes out of the duct 10 through the outlet passage 12. Further downstream, the fluid to the opposite side of the particle band passes out of the duct 10 through the outlet passage 14. The particles themselves continue to pass along the duct 10, to exit through a port 15 downstream of the two outlet passages 12,14.

It will be appreciated that the width of the duct 10, between the transducer 20 and reflector 22, is extremely small, 0.25mm in the example shown. We envisage, however, that the width of the duct may be even smaller, with advantage. It appears that the smaller the width of the duct, the less susceptible the fluid is to develop turbulence. Surprisingly, in view of the abrupt change of flow direction caused by the outlet passages 12,14, the fluid passes out of the duct 10, through these outlet passages, without creating turbulence and substantially free of particles.

Claims

1) An apparatus for performing the manipulation of particles suspended in a fluid, the apparatus comprising a duct for the flow of the fluid in which particles are suspended, and means for establishing, in a predetermined longitudinal portion of the duct, an acoustic standing wave field which extends across the width of the duct, the duct being provided, downstream of said portion in which the acoustic standing wave field is present, with at least one outlet passage which provides for an abrupt change of direction of the flowing fluid.

2) An apparatus as claimed in claim 1, arranged so that a single nodal plane is established in the acoustic standing wave field, generally mid-way between opposite sides of said duct.

3) An apparatus as claimed in claim 1 or 2, in which said duct is formed with first and second outlet passages in opposite sides of said duct.

4) An apparatus as claimed in any preceding claim, in which the or each outlet passage extends outwardly from said duct at an angle greater than 45°.

5) An apparatus as claimed in claim 4, in which the or each outlet passage extends outwardly from said duct at an angle greater than 60°

6) An apparatus as claimed in claim 5, in which the or each outlet passage extends outwardly from said duct at substantially 90°.

7) An apparatus as claimed in any preceding claim, in

which said duct has a generally uniform, rectangular cross-section.

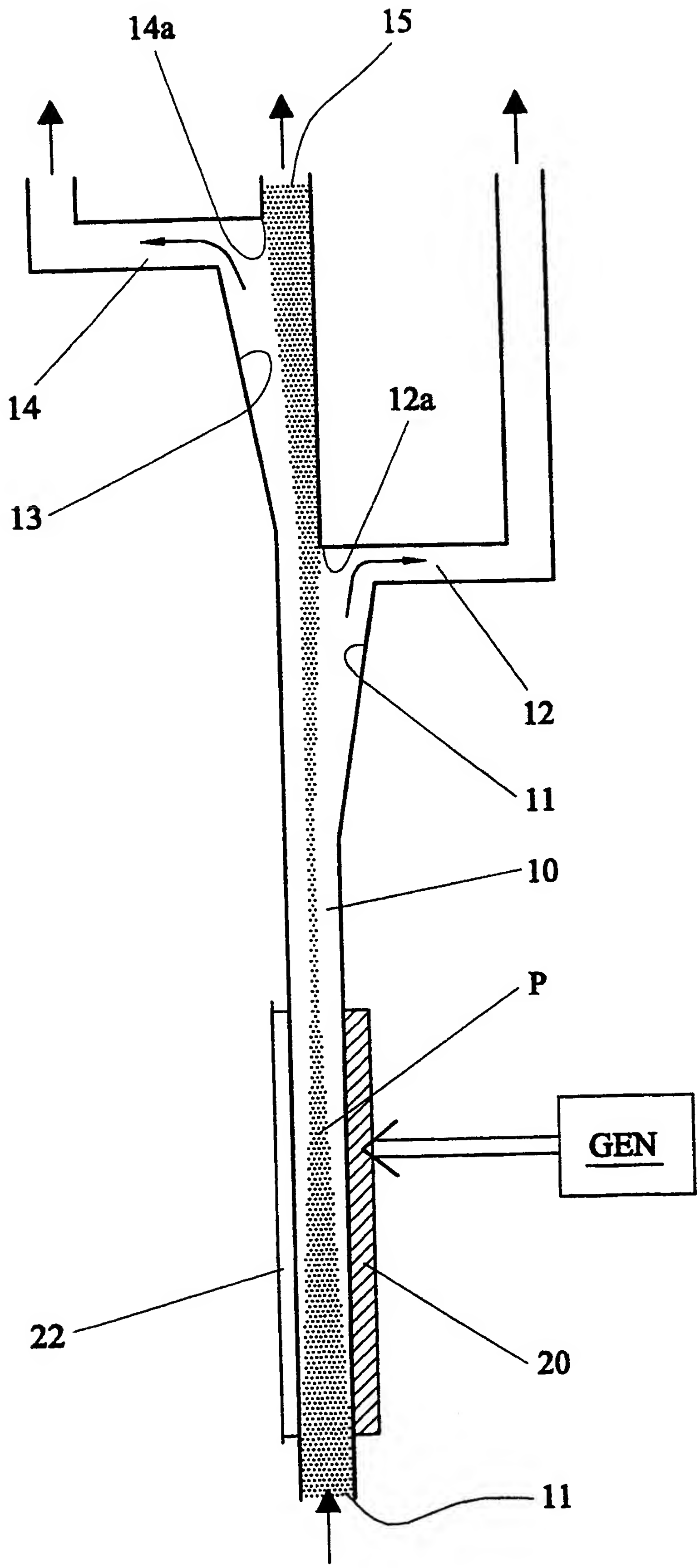
8) An apparatus as claimed in any preceding claim, in which the or each outlet passage has a generally uniform, rectangular cross-section.

9) An apparatus as claimed in any preceding claim in which the side of the duct, adjacent and upstream of the or each outlet passage, is inclined outwardly.

10) An apparatus as claimed in any preceding claim, in which the junction between the or each outlet passage and the corresponding side of the duct, downstream of the outlet passage, is rounded off.

11) An apparatus as claimed in any preceding claim, in which said duct is arranged generally vertical and for the fluid to flow upwardly along it.

12) A method of performing the manipulation of particles suspended in a fluid, the method comprising the steps of providing a duct, producing a flow of fluid along the duct, the fluid having particles suspended therein, establishing an acoustic standing wave field which extends across the width of the duct, in a predetermined longitudinal portion of the duct, and causing the fluid to undergo an abrupt change of direction into an outlet passage from the duct, at a position downstream of said portion in which the acoustic standing wave field is present.


14a
15
14
12a
13
12
11
10
P
GEN
22
20
11

INTERNATIONAL SEARCH REPORT

Inter.[illegible]lication No
PCT/GB[illegible]/00101

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B01D43/00 B01J19/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B01D B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 773 055 A (HITACHI ,LTD.) 14 May 1997 (1997-05-14) the whole document	1-7,12
A	WO 98 50133 A (UNIVERSITY COLLEGE CARDIFF CONSULTANTS) 12 November 1998 (1998-11-12) cited in the application claim 1; figure 1	1,12
A	P.H.BRODEUR: 1994 IEEE ULTRASONIC SYMPOSIUM,1 November 1994 (1994-11-01), pages 1359-1362, XP000525095 the whole document	1,12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 April 2000	02/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Bertram, H

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Info[illegible] on patent family members

Inter. [illegible]onal Application No
PCT/G[illegible]/00101

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 773055 A	14-05-1997	JP 9122480 A US 5902489 A	13-05-1997 11-05-1999
WO 9850133 A	12-11-1998	AU 7223798 A GB 2340769 A	27-11-1998 01-03-2000